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Tjæreborg Wind Turbine
4. dynamic inflow measurement

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VK- 204	Remarks :	Date/ sign. 25 Oct. 1991 *Stig Øye*
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Summary :

This paper presents results from the fourth measurement campaign at the Tjæreborg Wind Turbine during operation with stepwise pitch angle changes. The measurements cover one hour of operation at wind speeds between 7 and 10 m/s averaging approximately 8.7 m/s.

1. Description of the measured timeseries.

The fourth 'dynamic inflow' measurement campaign at the Tjæreborg Wind Turbine took place on 19 September 1991. In all, six timeseries of 10 minutes each were recorded during a period of 1 hour. For each timeseries a plot of wind speed at hub height, pitch angle, flapwise root bending moment of blade 2 and the generator power are shown on pages 7 to 12.

The measured wind speed varies from 5.3 m/s to 10.6 m/s, but comparing the generator power with the measured power curve of the turbine, the average wind over the rotor disc can be estimated to between 7 m/s and 10 m/s with an average of 8.7 m/s.

The zero points of the measured blade root bending moments, shaft torque and electric power have all been adjusted according to a measurement on the turbine during a normal stop followed by idling, which took place directly after the last timeseries. The zero point of the pitch angle was adjusted according to a calibration which took place on the following day.

During this measurement campaign the flapwise bending moment strain gauges of blade 1 were defective. On the other hand, the strain gauge measurement of the main shaft torque was working, thereby eliminating the need to synthesize this signal from the measured high speed shaft torque as done previously. The exact calibration of the main shaft torque signal is not completely verified at present, but the calibration used is believed to be correct or giving values a few percent too high. The new torque signal can also be seen to contain higher frequencies than before. The explanation has been found to be a low pass filter in the high speed shaft torque signal amplifier. The filter was set to 2 Hz instead of the usual 10 Hz.

During the experiment the pitch angle was stepped from 0.1 to 3.7 deg and back with a cycling time of 57.8 seconds. This was done by a new method which was able to produce steps with maximum pitch rate in both directions.

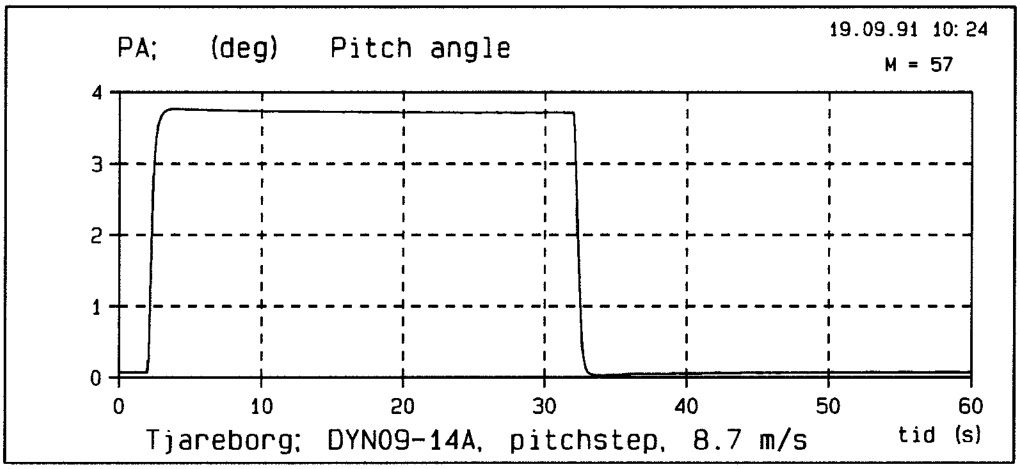
2. Average step response.

The same averaging procedure as described in AFM NOTAT VK-189 and VK-198 has been used here. The average response is the result of a total of 58 upwards going pitchsteps and 59 downwards steps. As in VK-198 the pitchsteps are positioned at t=2 and t=32 seconds in the averaged series.

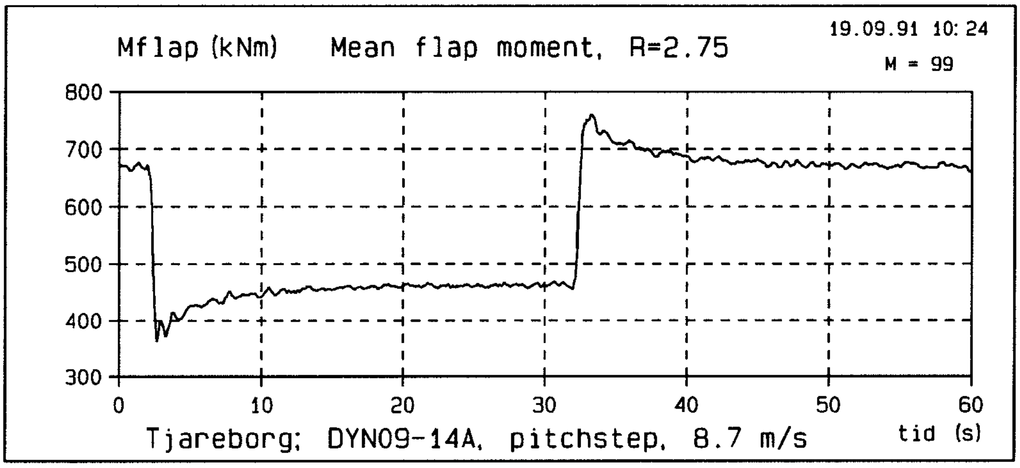
Page 3 shows the resulting response of the mean value of the 2 functioning flapwise moments, of the main shaft torque and of the generator power. Page 4 shows the response of the 2 individual flapwise blade root moments. Page 5 and 6 show the same as page 3, but the time axis is expanded around the pitchsteps.

The averaged response shows very little 'noise' from turbulence and tower passage. This is a result of the long measuring period and the relatively large size of the pitch step, which both increase the 'signal-to-noise ratio'. The turbulence was also less than during the previous experiments.

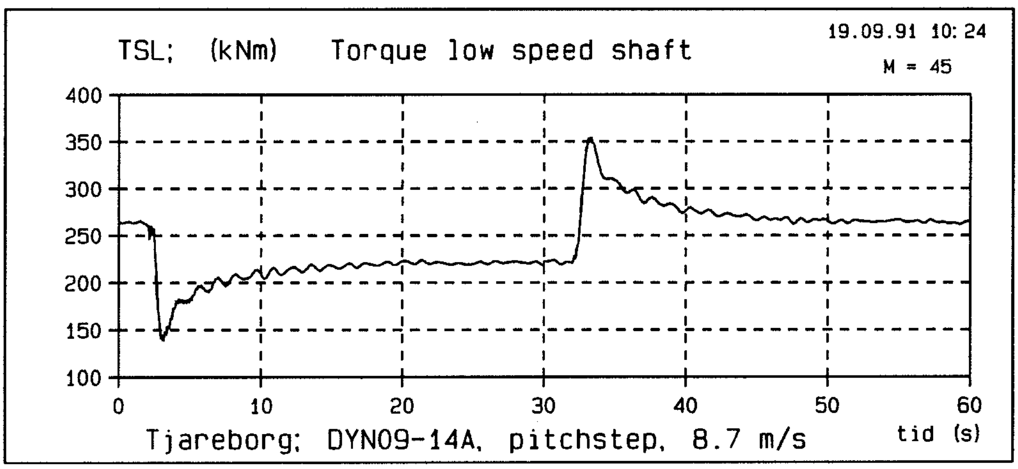
The 3-P components (1.1 Hz) are surprisingly small this time probably due to a more favorable phasing of the individual timeseries. The remaining ripples in the torque and power signals are believed to be real dynamic responses caused by the pitch steps. The frequency of 0.75-0.80 Hz is probably caused by excitation of the tower while the 4.5 Hz response could be the 2. inplane symmetric rotor mode. In this mode, the hub rotates opposite to the blade tips and the generator. However, the mechanism involved in the excitation of this particular mode is not known.



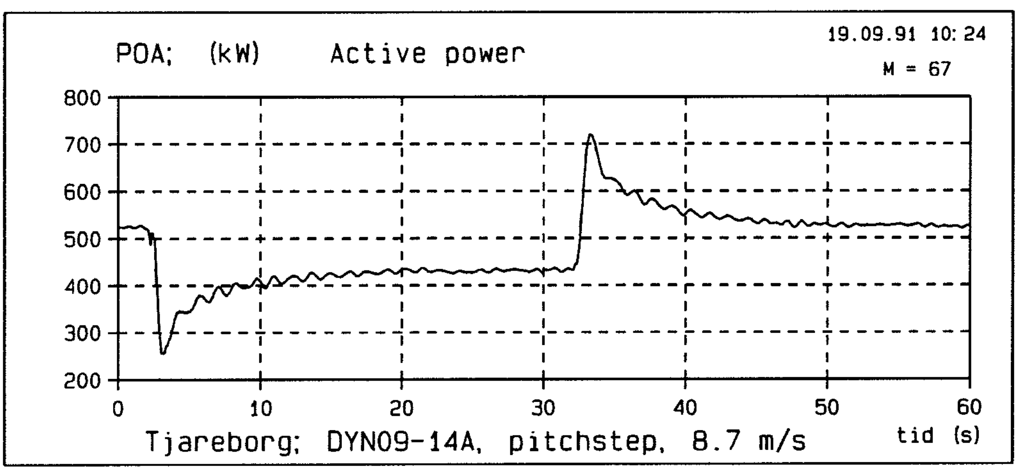
PA; (deg) Pitch angle
19.09.91 10: 24
M = 57
4
3
2
1
0
0 10 20 30 40 50 60
Tjareborg; DYN09-14A, pitchstep, 8.7 m/s
tid (s)



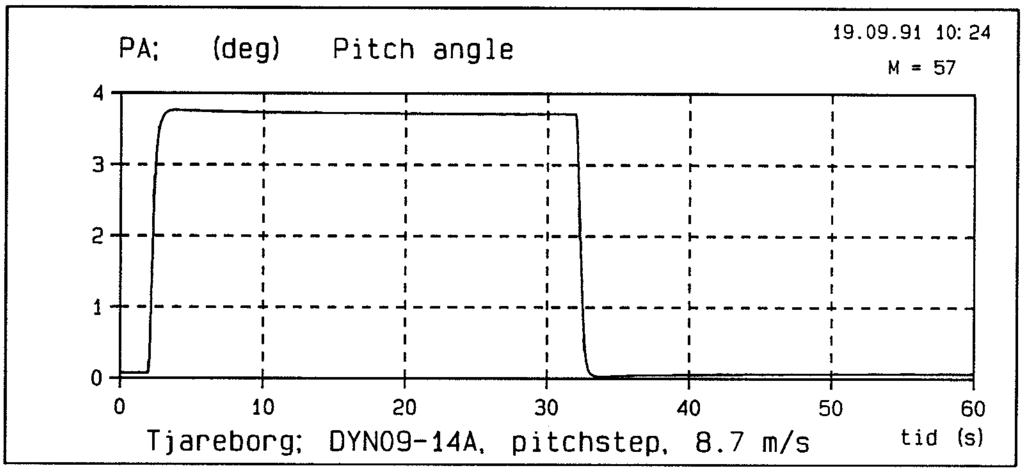
Mflap (kNm) Mean flap moment, R=2.75
19.09.91 10: 24
M = 99
800
700
600
500
400
300
0 10 20 30 40 50 60
Tjareborg; DYN09-14A, pitchstep, 8.7 m/s
tid (s)

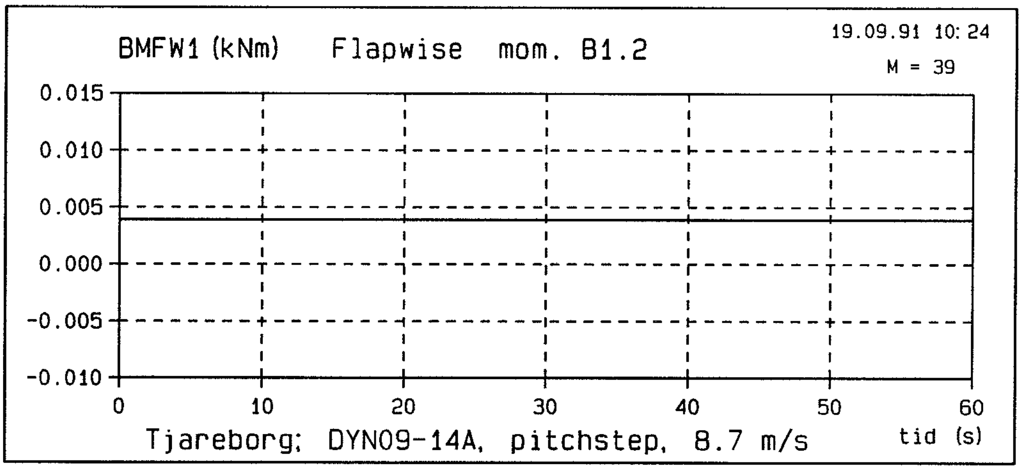


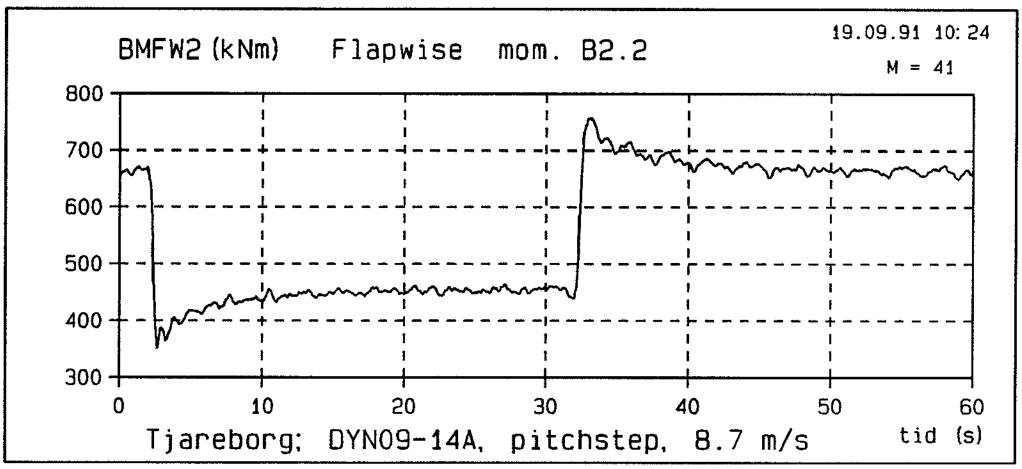
TSL; (kNm) Torque low speed shaft
19.09.91 10: 24
M = 45
400
350
300
250
200
150
100
0 10 20 30 40 50 60
Tjareborg; DYN09-14A, pitchstep, 8.7 m/s
tid (s)

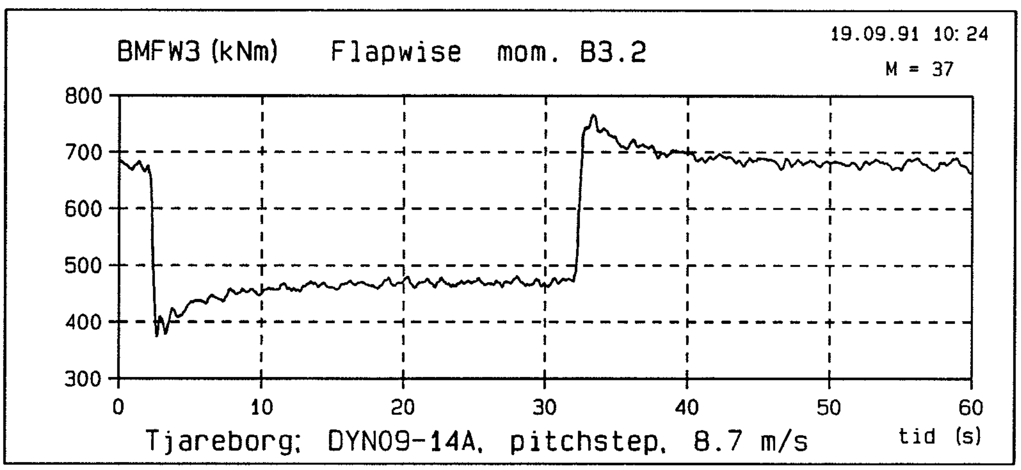


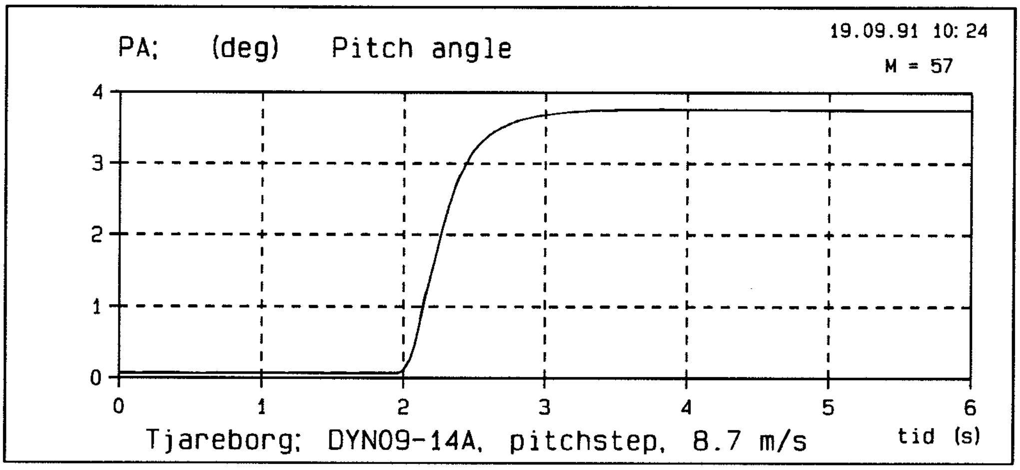
POA; (kW) Active power
19.09.91 10: 24
M = 67
800
700
600
500
400
300
200
0 10 20 30 40 50 60
Tjareborg; DYN09-14A, pitchstep, 8.7 m/s
tid (s)

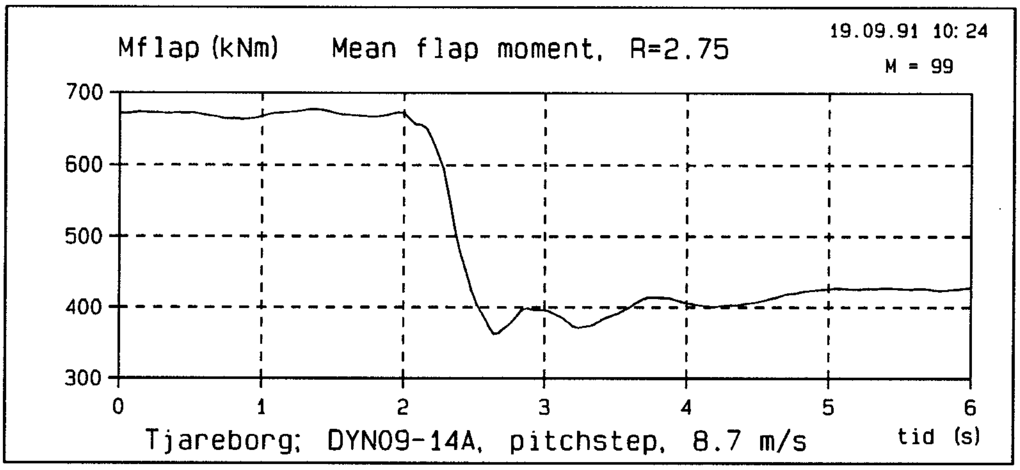

PA; (deg) Pitch angle
19.09.91 10: 24
M = 57
4
3
2
1
0
0
10
20
30
40
50
60
Tjareborg: DYN09-14A, pitchstep, 8.7 m/s
tid (s)

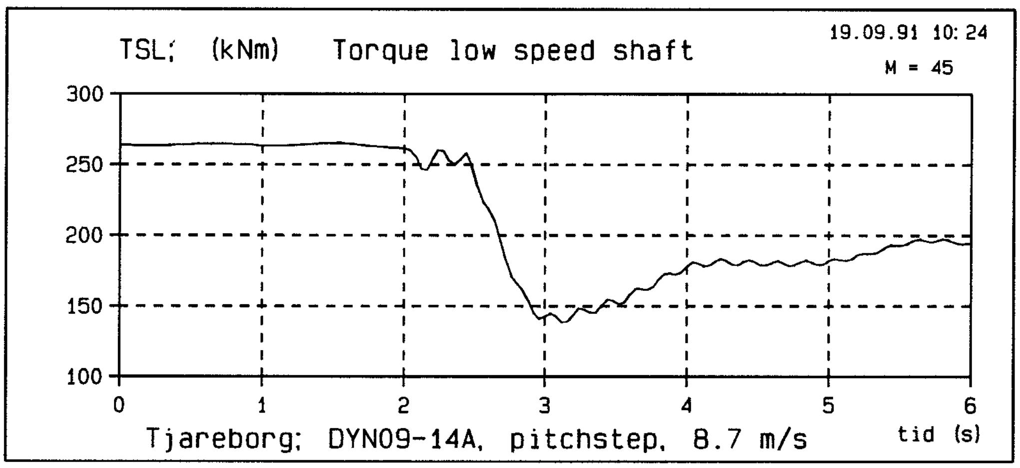

BMFW1 (kNm) Flapwise mom. B1.2
19.09.91 10: 24
M = 39
0.015
0.010
0.005
0.000
-0.005
-0.010
0
10
20
30
40
50
60
Tjareborg: DYN09-14A, pitchstep, 8.7 m/s
tid (s)

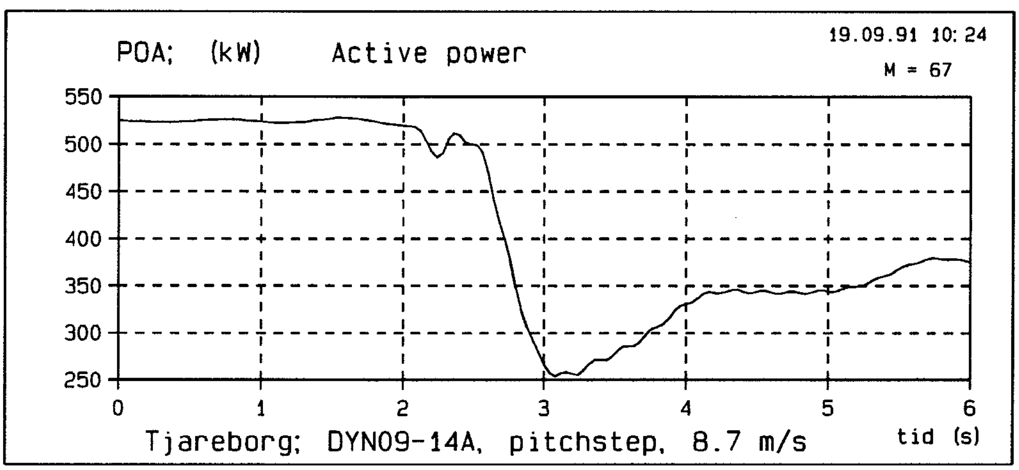

BMFW2 (kNm) Flapwise mom. B2.2
19.09.91 10: 24
M = 41
800
700
600
500
400
300
0
10
20
30
40
50
60
Tjareborg: DYN09-14A, pitchstep, 8.7 m/s
tid (s)

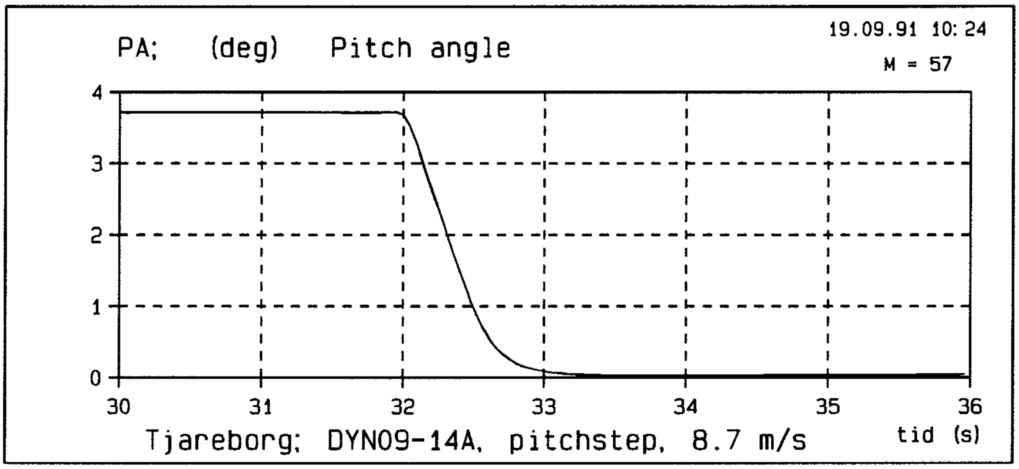

BMFW3 (kNm) Flapwise mom. B3.2
19.09.91 10: 24
M = 37
800
700
600
500
400
300
0
10
20
30
40
50
60
Tjareborg: DYN09-14A, pitchstep, 8.7 m/s
tid (s)

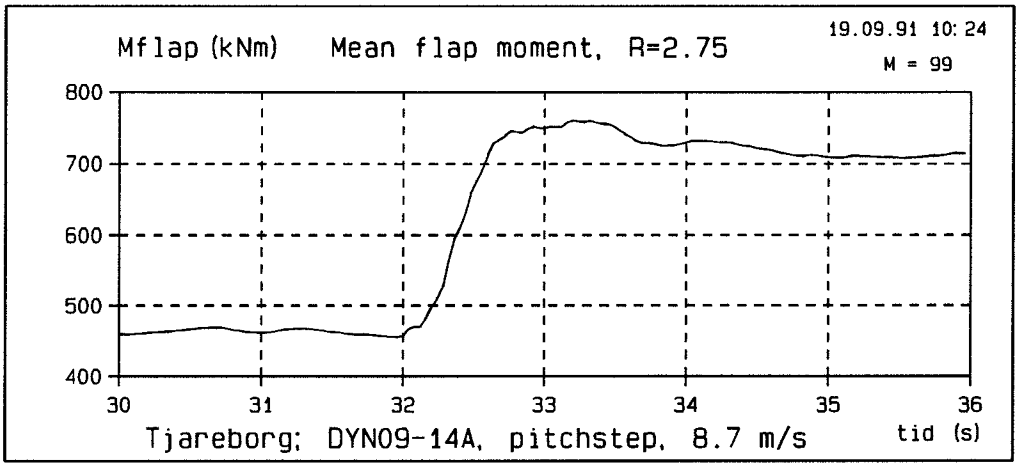

PA; (deg) Pitch angle
19.09.91 10:24
M = 57
4
3
2
1
0
0 1 2 3 4 5 6
Tjareborg; DYN09-14A, pitchstep, 8.7 m/s
tid (s)

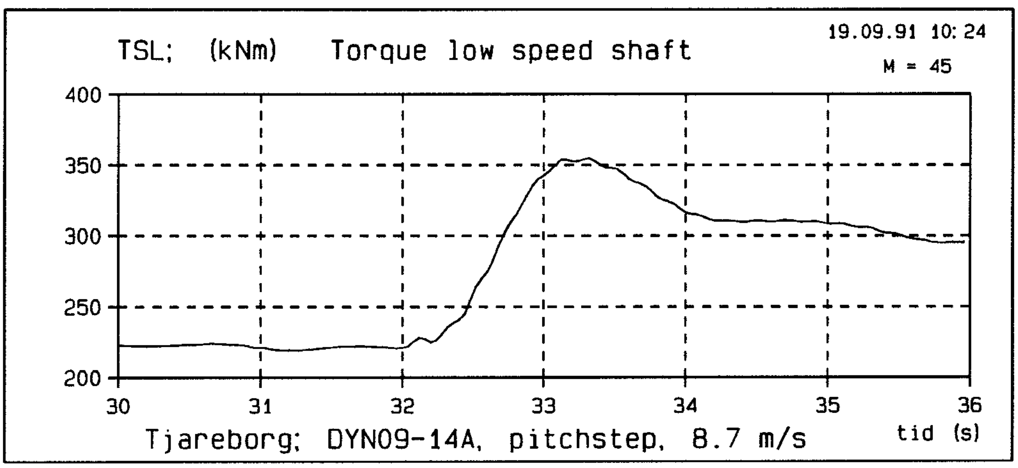

Mflap (kNm) Mean flap moment, R=2.75
19.09.91 10:24
M = 99
700
600
500
400
300
0 1 2 3 4 5 6
Tjareborg; DYN09-14A, pitchstep, 8.7 m/s
tid (s)

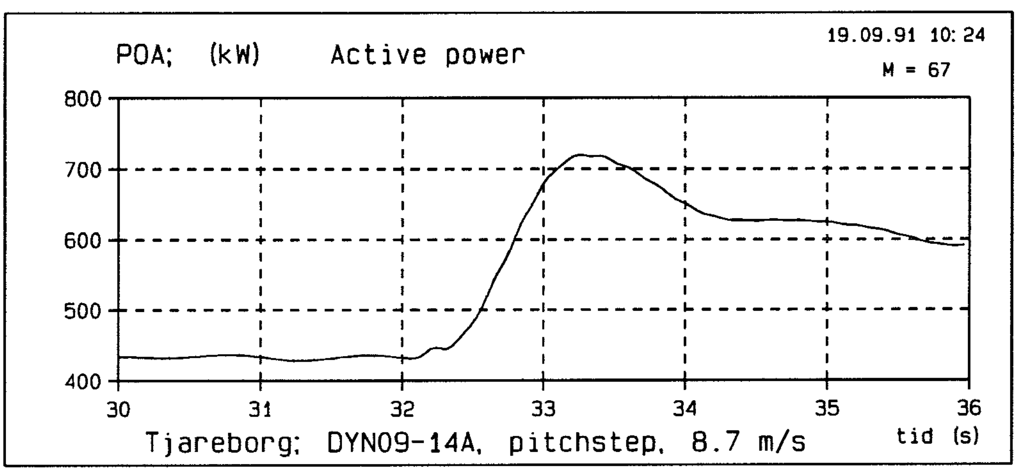

TSL; (kNm) Torque low speed shaft
19.09.91 10:24
M = 45
300
250
200
150
100
0 1 2 3 4 5 6
Tjareborg; DYN09-14A, pitchstep, 8.7 m/s
tid (s)

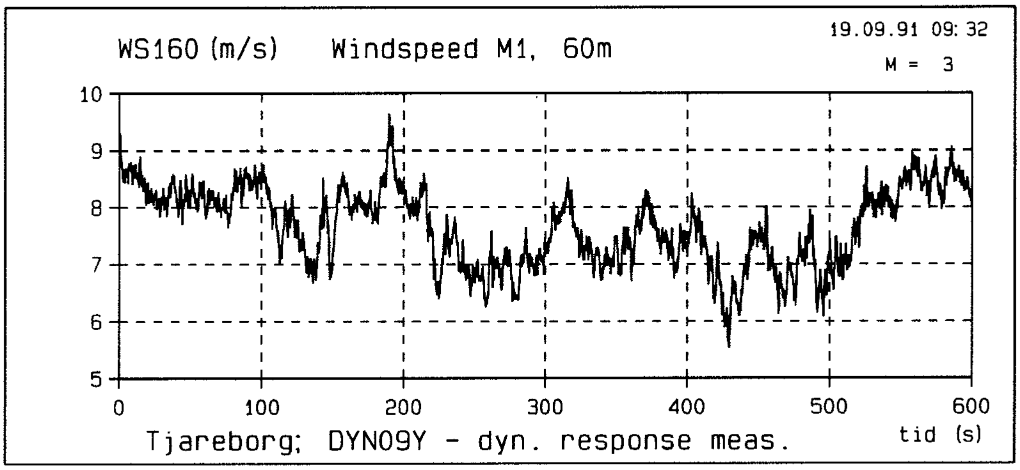

POA; (kW) Active power
19.09.91 10:24
M = 67
550
500
450
400
350
300
250
0 1 2 3 4 5 6
Tjareborg; DYN09-14A, pitchstep, 8.7 m/s
tid (s)

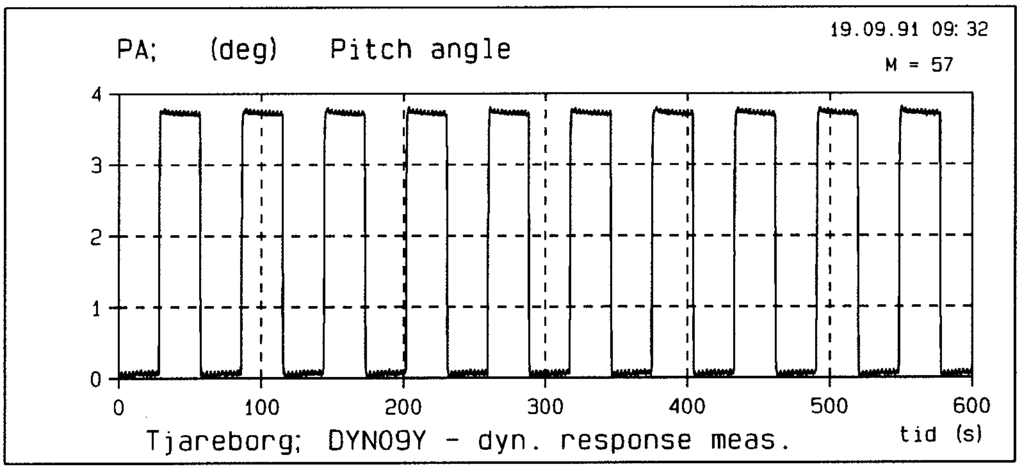

PA; (deg) Pitch angle
19.09.91 10:24
M = 57
4
3
2
1
0
30
31
32
33
34
35
36
Tjareborg: DYN09-14A, pitchstep, 8.7 m/s
tid (s)

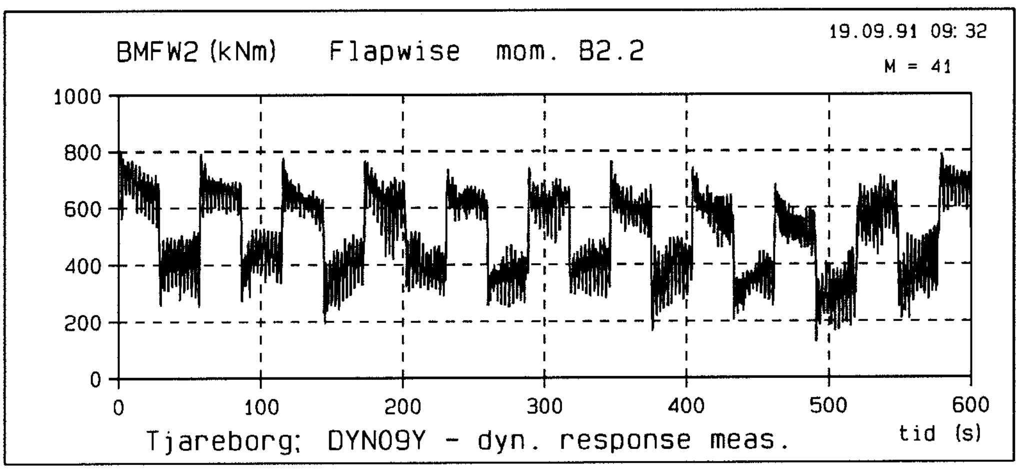

Mflap (kNm) Mean flap moment, R=2.75
19.09.91 10:24
M = 99
800
700
600
500
400
30
31
32
33
34
35
36
Tjareborg: DYN09-14A, pitchstep, 8.7 m/s
tid (s)

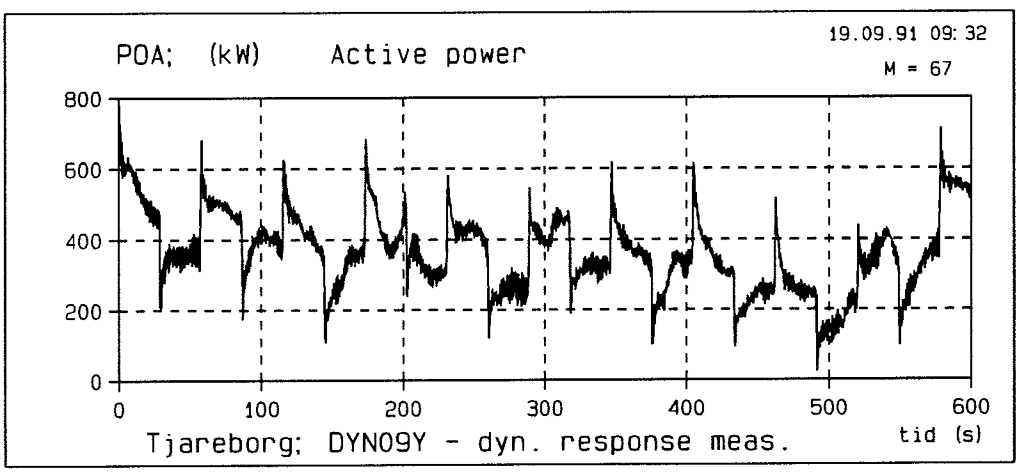

TSL; (kNm) Torque low speed shaft
19.09.91 10:24
M = 45
400
350
300
250
200
30
31
32
33
34
35
36
Tjareborg: DYN09-14A, pitchstep, 8.7 m/s
tid (s)

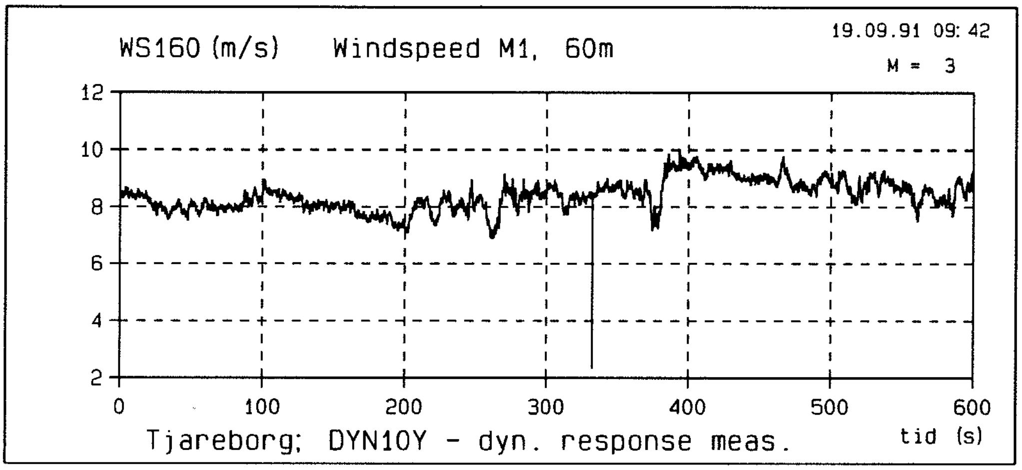

POA; (kW) Active power
19.09.91 10:24
M = 67
800
700
600
500
400
30
31
32
33
34
35
36
Tjareborg: DYN09-14A, pitchstep, 8.7 m/s
tid (s)

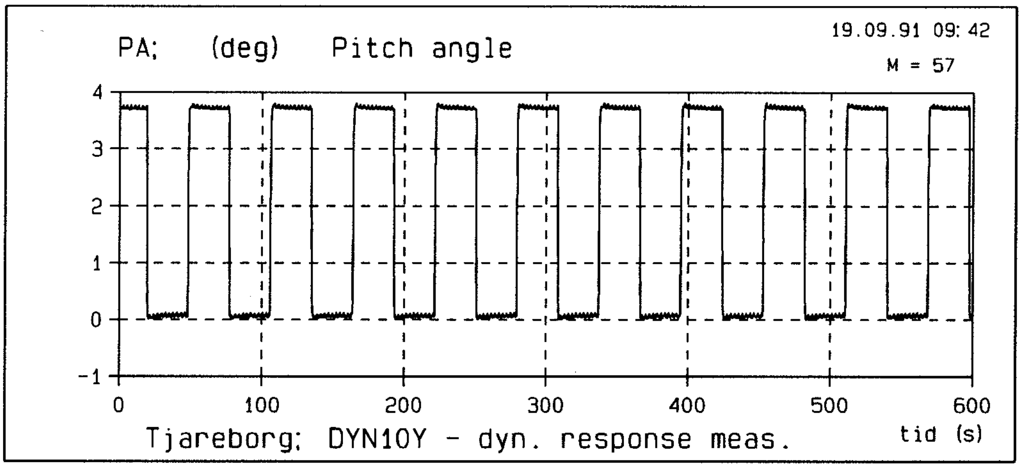

WS160 (m/s) Windspeed M1, 60m
19.09.91 09:32
M = 3
10
9
8
7
6
5
0
100
200
300
400
500
600
Tjareborg; DYN09Y - dyn. response meas.
tid (s)

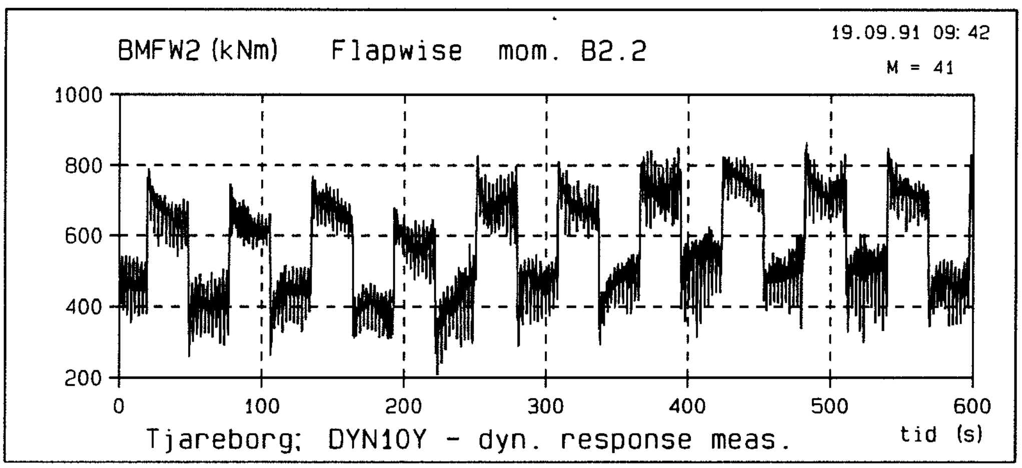

PA; (deg) Pitch angle
19.09.91 09:32
M = 57
4
3
2
1
0
0
100
200
300
400
500
600
Tjareborg; DYN09Y - dyn. response meas.
tid (s)

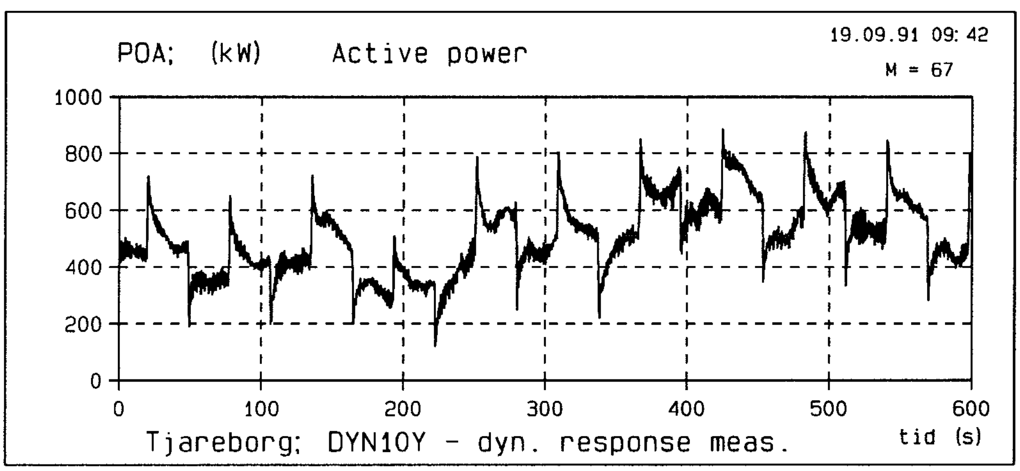

BMFW2 (kNm) Flapwise mom. B2.2
19.09.91 09:32
M = 41
1000
800
600
400
200
0
0
100
200
300
400
500
600
Tjareborg; DYN09Y - dyn. response meas.
tid (s)

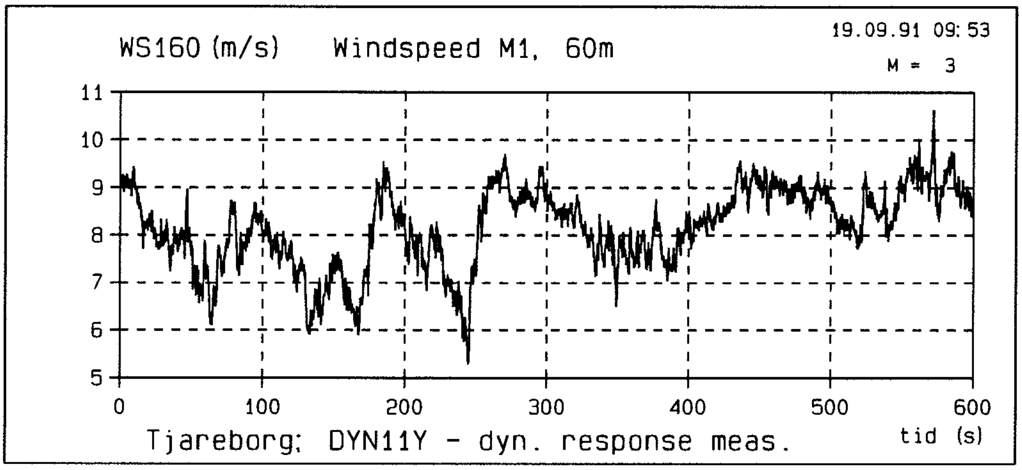

POA; (kW) Active power
19.09.91 09:32
M = 67
800
600
400
200
0
0
100
200
300
400
500
600
Tjareborg; DYN09Y - dyn. response meas.
tid (s)

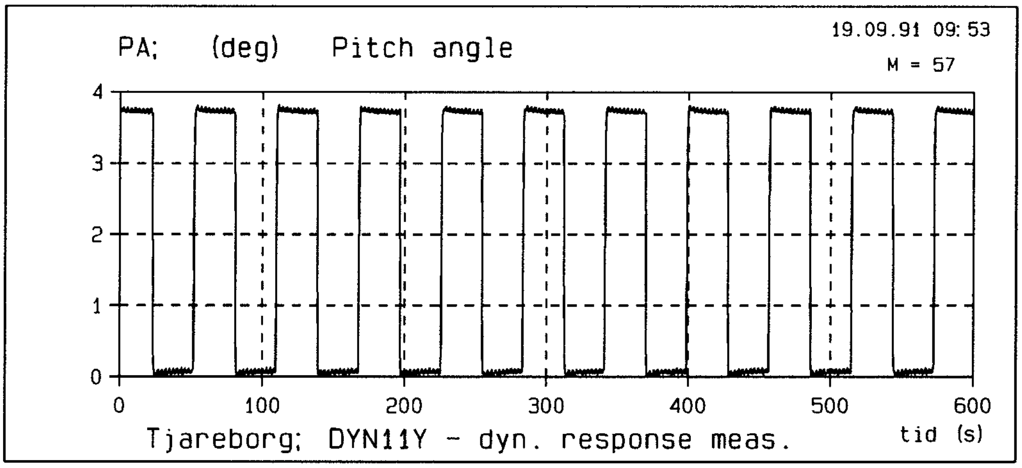

WS160 (m/s) Windspeed M1, 60m
19.09.91 09:42
M = 3
Tjareborg; DYN10Y - dyn. response meas.
tid (s)

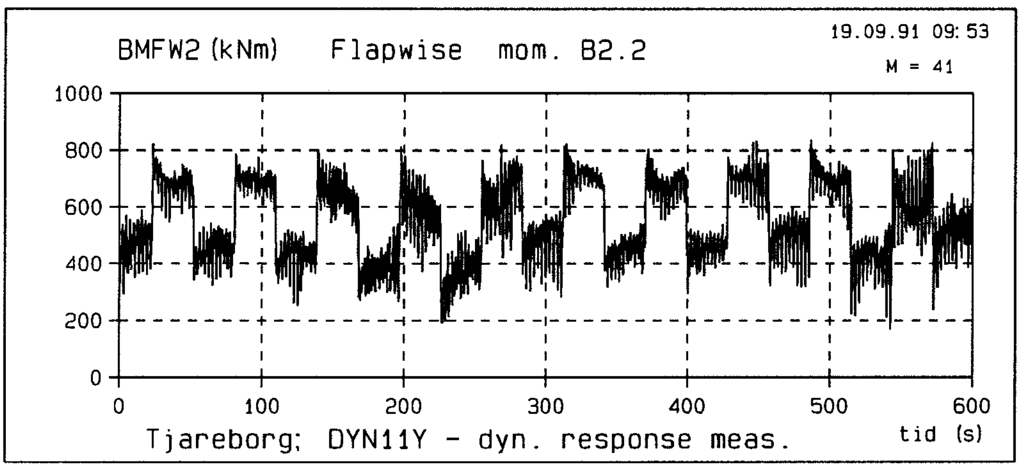

PA; (deg) Pitch angle
19.09.91 09:42
M = 57
Tjareborg; DYN10Y - dyn. response meas.
tid (s)

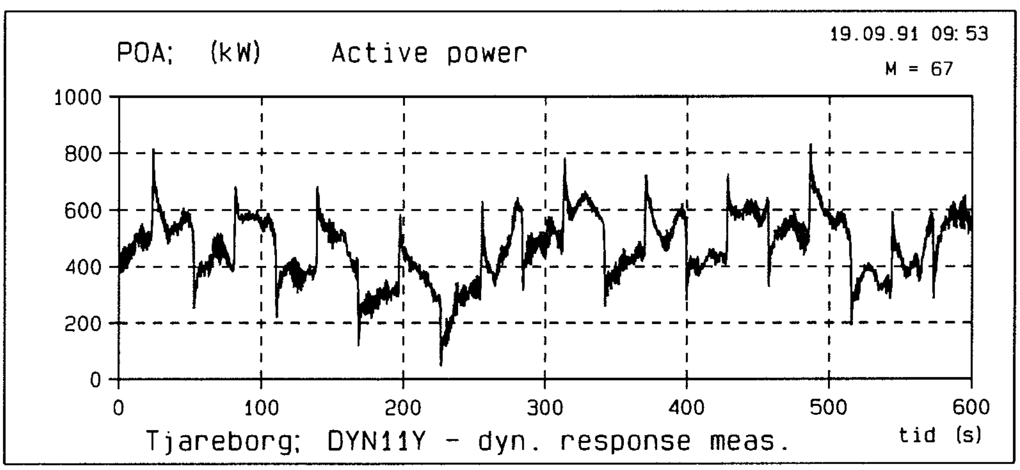

BMFW2 (kNm) Flapwise mom. B2.2
19.09.91 09:42
M = 41
Tjareborg; DYN10Y - dyn. response meas.
tid (s)

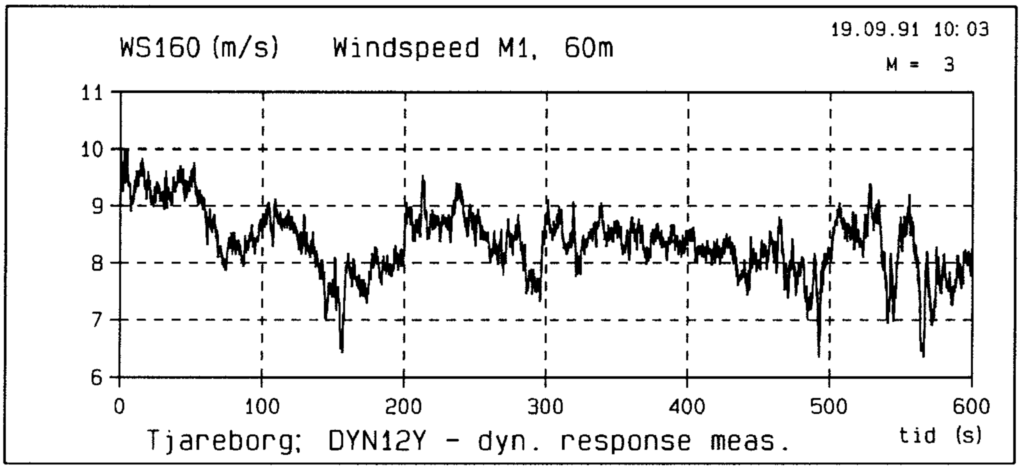

POA; (kW) Active power
19.09.91 09:42
M = 67
Tjareborg; DYN10Y - dyn. response meas.
tid (s)


WS160 (m/s) Windspeed M1, 60m
19.09.91 09:53
M = 3
11
10
9
8
7
6
5
0
100
200
300
400
500
600
Tjareborg; DYN11Y - dyn. response meas.
tid (s)

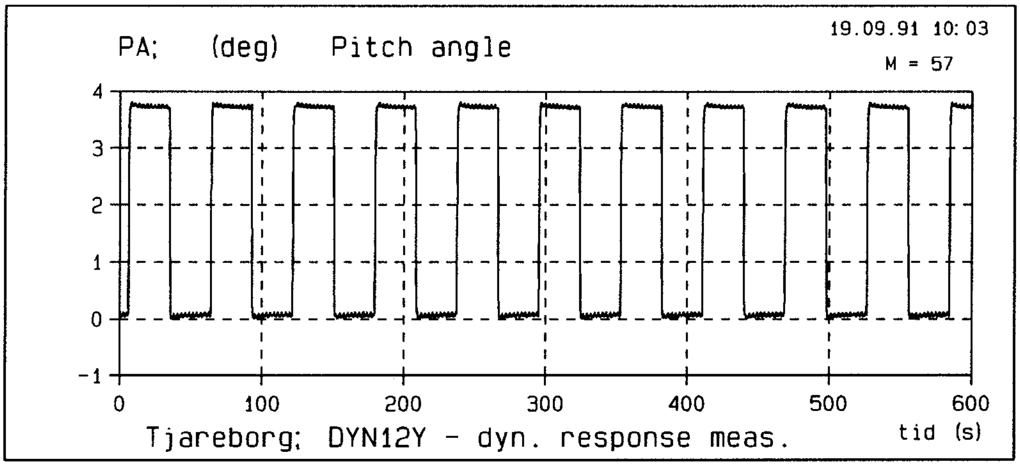

PA; (deg) Pitch angle
19.09.91 09:53
M = 57
4
3
2
1
0
0
100
200
300
400
500
600
Tjareborg; DYN11Y - dyn. response meas.
tid (s)


BMFW2 (kNm) Flapwise mom. B2.2
19.09.91 09:53
M = 41
1000
800
600
400
200
0
0
100
200
300
400
500
600
Tjareborg; DYN11Y - dyn. response meas.
tid (s)

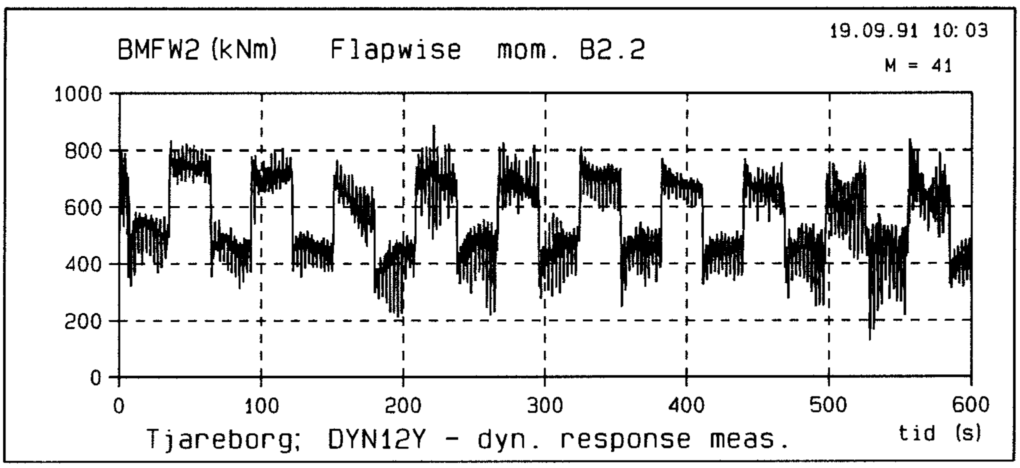

POA; (kW) Active power
19.09.91 09:53
M = 67
1000
800
600
400
200
0
0
100
200
300
400
500
600
Tjareborg; DYN11Y - dyn. response meas.
tid (s)



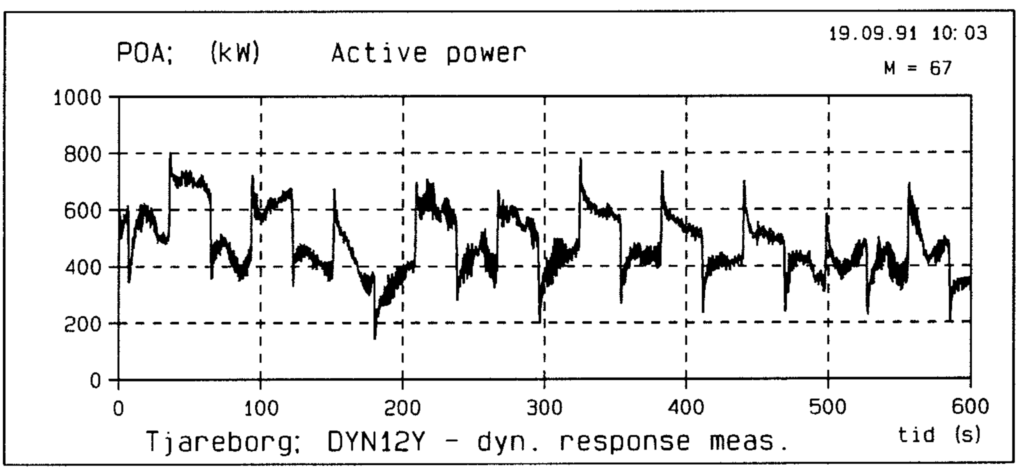
WS160 (m/s) Windspeed M1, 60m
19.09.91 10:03
M = 3
11
10
9
8
7
6
0
100
200
300
400
500
600
Tjareborg; DYN12Y - dyn. response meas.
tid (s)



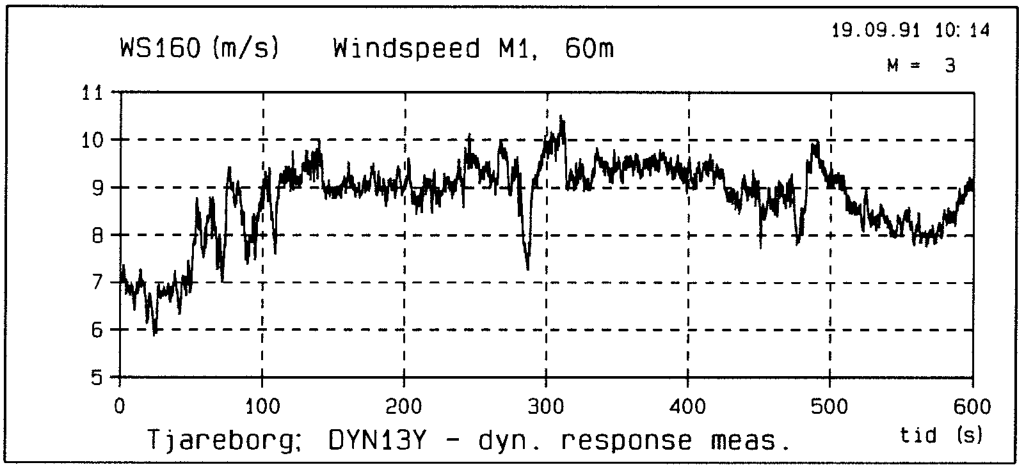
PA; (deg) Pitch angle
19.09.91 10:03
M = 57
4
3
2
1
0
-1
0
100
200
300
400
500
600
Tjareborg; DYN12Y - dyn. response meas.
tid (s)

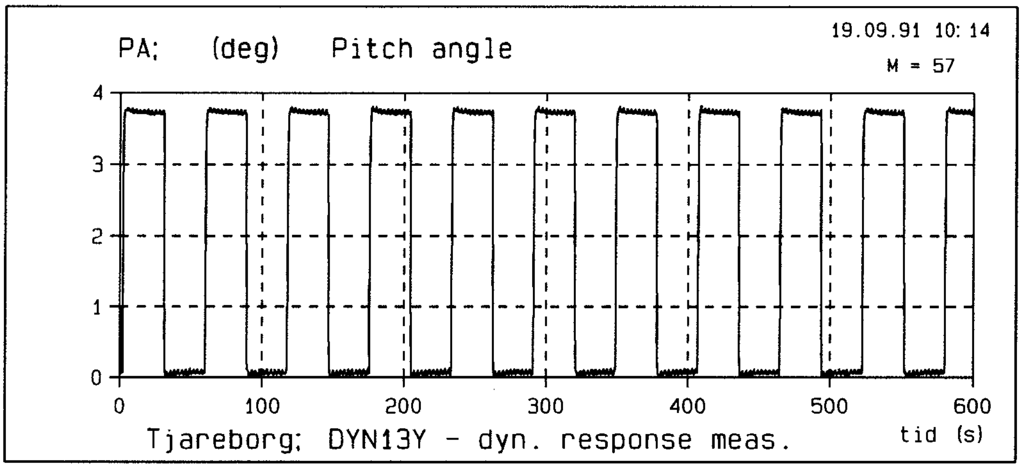


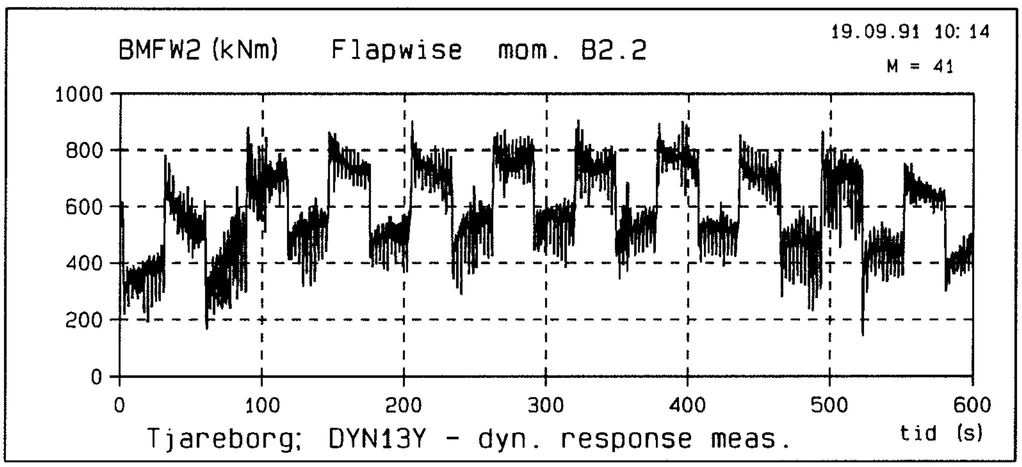
BMFW2 (kNm) Flapwise mom. B2.2
19.09.91 10:03
M = 41
1000
800
600
400
200
0
0
100
200
300
400
500
600
Tjareborg; DYN12Y - dyn. response meas.
tid (s)

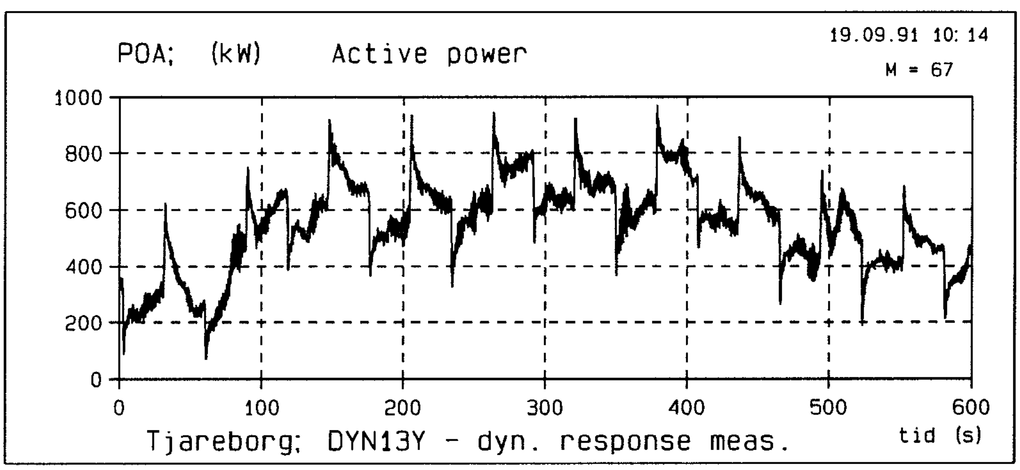


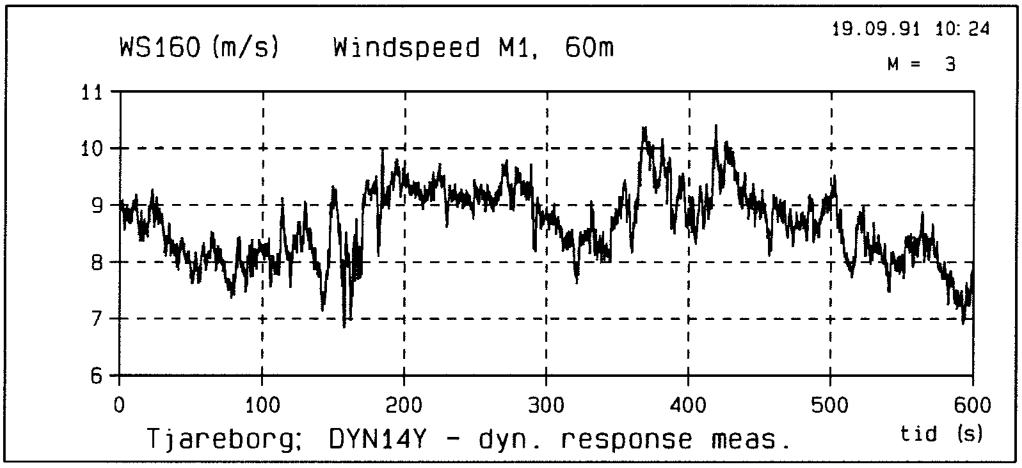
POA; (kW) Active power
19.09.91 10:03
M = 67
1000
800
600
400
200
0
0
100
200
300
400
500
600
Tjareborg; DYN12Y - dyn. response meas.
tid (s)

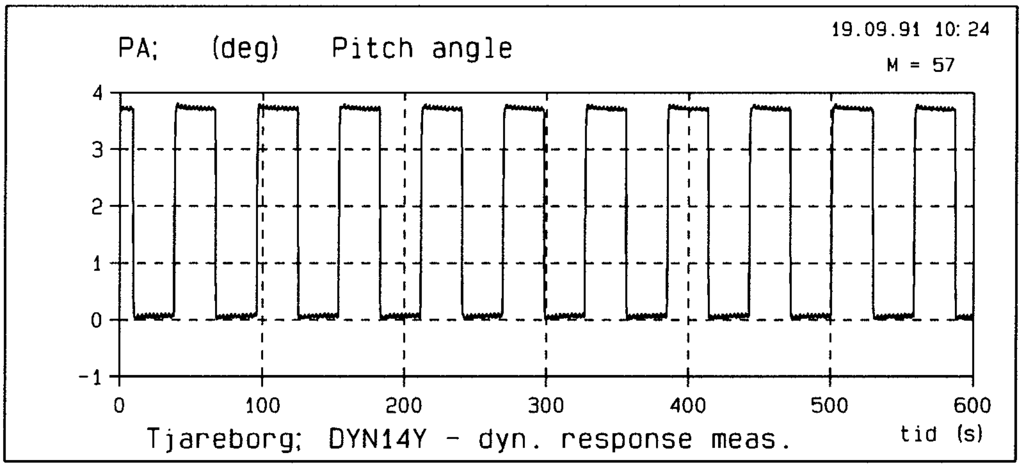

WS160 (m/s) Windspeed M1, 60m
19.09.91 10:14
M = 3
11
10
9
8
7
6
5
0
100
200
300
400
500
600
Tjareborg; DYN13Y - dyn. response meas.
tid (s)

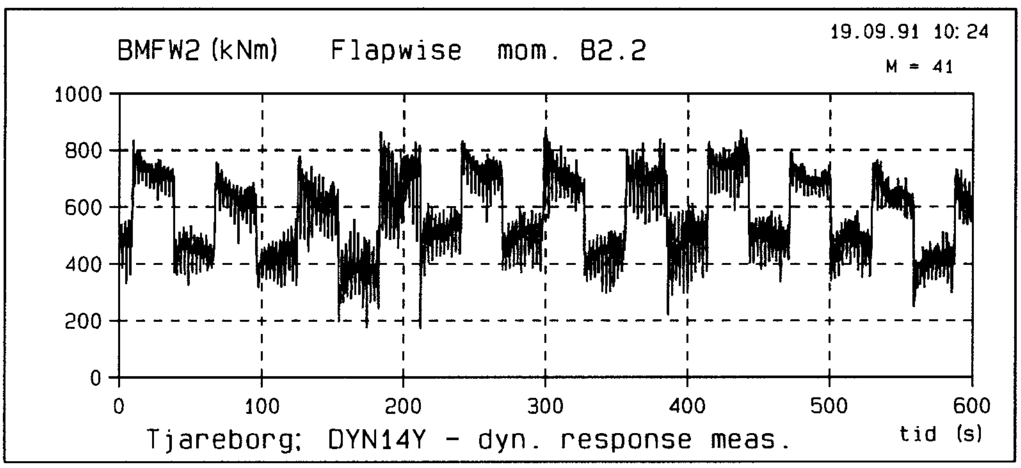

PA; (deg) Pitch angle
19.09.91 10:14
M = 57
4
3
2
1
0
0
100
200
300
400
500
600
Tjareborg; DYN13Y - dyn. response meas.
tid (s)

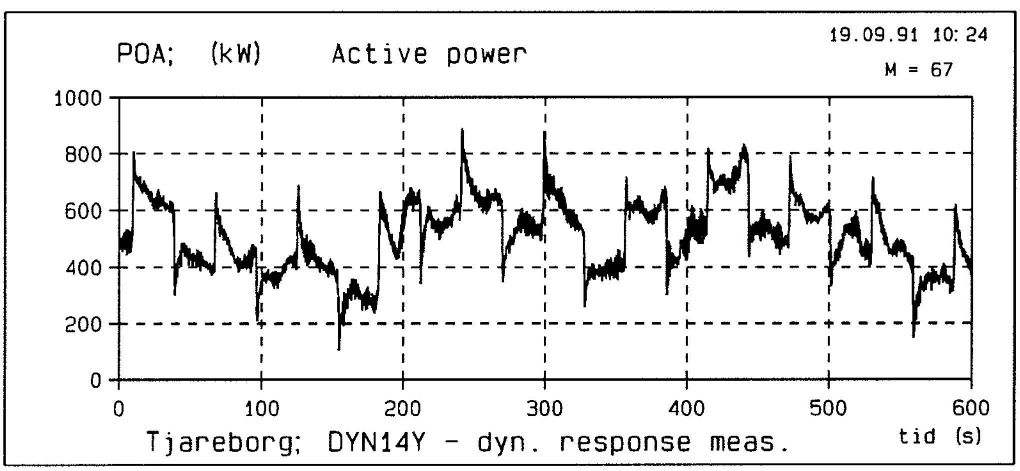

BMFW2 (kNm) Flapwise mom. B2.2
19.09.91 10:14
M = 41
1000
800
600
400
200
0
0
100
200
300
400
500
600
Tjareborg; DYN13Y - dyn. response meas.
tid (s)


POA; (kW) Active power
19.09.91 10:14
M = 67
1000
800
600
400
200
0
0
100
200
300
400
500
600
Tjareborg; DYN13Y - dyn. response meas.
tid (s)


WS160 (m/s) Windspeed M1, 60m
19.09.91 10:24
M = 3
11
10
9
8
7
6
0
100
200
300
400
500
600
Tjareborg; DYN14Y - dyn. response meas.
tid (s)


PA; (deg) Pitch angle
19.09.91 10:24
M = 57
4
3
2
1
0
-1
0
100
200
300
400
500
600
Tjareborg; DYN14Y - dyn. response meas.
tid (s)


BMFW2 (kNm) Flapwise mom. B2.2
19.09.91 10:24
M = 41
1000
800
600
400
200
0
0
100
200
300
400
500
600
Tjareborg; DYN14Y - dyn. response meas.
tid (s)


POA; (kW) Active power
19.09.91 10:24
M = 67
1000
800
600
400
200
0
0
100
200
300
400
500
600
Tjareborg; DYN14Y - dyn. response meas.
tid (s)